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Changes in Strength Over Time Among Polio Survivors

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ABSTRACT

Objective: To study changes in the strength of a variety of muscle groups in polio survivors over a 6-9 month period.

Design: Longitudinal study of a cohort of polio survivors

Setting: A research laboratory at Moss Rehabilitation Research Institute

Participants: One hundred twenty subjects (57 men and 63 women) were studied on three occasions, each 3-5 months apart. Subjects were recruited through the Einstein-Moss Post-Polio Management Program, newspaper advertisements, and polio support groups. Demographic, medical history data, and strength data were obtained. Subjects were classified based on whether or not they reported subjective feelings of increasing weakness at the initial visit.

Main Outcome Measures: Isometric strength of 30 muscle groups (16 in upper extremities and 14 in lower extremities) was measured using a hand-held dynamometer.

Results: The data were analyzed in two separate groups: upper extremity muscles and lower extremity muscles. Results for the upper extremity muscles revealed evidence of a significant deterioration in strength over the study interval. The amount of deterioration differed among muscles. The results also showed that the rate of deterioration increased with increasing age. For the lower extremities, there was also evidence of deterioration in strength in the flexor muscles of the ankle, hip, and knee. The rate of deterioration in these muscles was not strongly related to age, gender, symptom status, or history of residual weakness.

Conclusions: Our results indicate that strength is deteriorating among polio survivors. However, this deterioration is not occurring in the extensor or so-called "weight-bearing" muscles, but is instead occurring in many of the upper extremity muscle groups and in the flexor muscles in the lower extremities.

INTRODUCTION

Post-polio syndrome (PPS) is a term used to describe a collection of symptoms experienced by many polio survivors after several decades of functional stability. These symptoms include muscle and joint pain, muscle weakness, fatigue and intolerance to cold.[1,2,3,]

Several functional and pathophysiologic mechanisms have been suggested for PPS, but none has been proven. There is some controversy regarding whether the symptoms involved are due to the primary degeneration of motor units previously affected by polio versus the attrition of motor neurons associated with normal aging.[4,5,6] Another theory involves overuse or "overwork weakness" where the functional demands exceed the capacity of polio-affected muscles.[7] Other authors have suggested that disuse may play an important role, while still others have suggested that increased stress due to weight gain may be an important factor.[8,9,10]

Currently, there is no diagnostic test for PPS. It is usually diagnosed by excluding other medical or neurological disorders that may produce similar symptoms. For example, the symptoms experienced by polio survivors with PPS are similar to those experienced in patients with chronic fatigue syndrome.[11] Fibromyalgia is another neuromuscular disorder with similar symptoms, which is common among middle-aged, deconditioned persons. It is possible that the chronic use of weakened muscles or the compensatory use of other muscles with "normal" levels of strength may predispose polio survivors to this type of disorder.[11]

Post-polio syndrome is believed to be slowly progressive. Previous studies have examined whether strength decreases at an accelerated rate over time in polio survivors. These studies have followed the strength in polio survivors over periods ranging from one year to just over eight years with contradictory results (Table 1).

Insert Table 1 about here.

Several of these studies focused on symptomatic polio survivors, or those who reported increasing muscle weakness (Dalakas, et al, 1986; Musat et al., 1987; Munin et al., 1991) while others have compared symptomatic (unstable) with asymptomatic (stable) polio survivors (Grimby et al., 1994, Ivanyi et al., 1996, Rodriquez et al., 1997). In each case, the results have been inconsistent with some studies reporting significant decreases in strength, others reporting no significant change, and still others reporting evidence of an increase in strength, even among those subjects who are reporting subjective feelings of increasing weakness.

In addition, most of the previous studies have limited their testing to only one or two muscle groups. The assumption is made that these muscle groups are representative of polio-affected muscles throughout the body. As shown in Table 1, many of the researchers have focused their attention on the quadriceps muscle in one leg that was affected by polio. What is not taken into account is the cumulative effects over time on the muscles which are used to compensate for those muscles left weakened by the polio virus. The one study, which did look at a fairly extensive list of muscle groups, reported a significant increase in isometric strength in 10 out of 22 muscle groups among subjects who were reporting problems with increasing muscle weakness.[11] The authors gave no explanation for this contradictory conclusion.

It is evident that more research is needed on the changes in the muscle strength of polio survivors over time in order to clarify some of these contradictions. The purpose of this study was to assess the strength of polio survivors in a comprehensive group of muscles and to determine whether there was a significant decrease in muscle strength over time. Gravity-eliminated positioning was used for the strength testing in order to enable us to include a more representative sample of the post-polio population.

METHOD

A total of 120 polio survivors (57 men and 63 women) participated in this study. Subjects were recruited through the Einstein-Moss Post-Polio Management Program, post-polio support groups, and advertisements in local newspapers. Inclusion criteria for all subjects were: 1) history of polio; 2) no other major disabilities, such as stroke, amputation, inflammatory arthritis, or peripheral neuropathy, that could cause muscle weakness; 3) no serious illnesses, such as severe emphysema, poorly controlled asthma, resting angina, or a recent heart attack, which would make a maximal strength test unsafe; and 4) no fractures or surgeries within the past six months, which might cause transient changes in strength. All subjects gave informed consent, and the hospital's Institutional Review Board approved the study protocol.

At the initial visit, each subject was asked to complete a standardized medical history form and a polio history questionnaire. As part of the polio history questionnaire, subjects were asked to specify their age at the time of the acute infection and the sites where they were left with residual weakness or paralysis. The seven possible sites were: neck, back, abdomen, left arm, left leg, right arm or right leg. Subjects were also asked if they had recently been experiencing problems with increasing weakness. Subjects who reported increasing weakness were classified as symptomatic and those who did not were classified as asymptomatic.

Following completion of the forms, height (cm) and weight (kg) were assessed using a standard scale. Isometric strength was then measured in 15 muscle groups bilaterally by one of three physical therapists using a Microfet2[a] hand-held dynamometer (HHD). The muscle groups involved were: wrist flexors and extensors, elbow flexors and extensors, shoulder abductors, external rotators, flexors, and extensors, hip abductors, flexors, and extensors, knee flexors and extensors, and ankle dorsiflexors and plantarflexors. All muscles were tested in gravity-eliminated positions. The postures, placement of the dynamometer, and stabilization points were standardized (Table 2). For each test, the subject pushed against the padded dynamometer force plate that the physical therapist held stationary. The subject was asked to slowly build to a maximal force over a period of 2-3 seconds and then hold this maximal effort for 3-4 seconds.

The peak force was measured in pounds. Each muscle group was measured a minimum of two times. Additional measurements were taken only if the first two varied by more than 10%. For very weak muscles with strengths less than 10 lb., measurements were repeated only if the difference between the first two measurements was greater than 1 lb. The maximum number of trials was four to prevent fatigue. If a subject reported any muscle or joint pain during testing, those trials were considered invalid. For each muscle group, the average of the valid trials was defined as the isometric maximal voluntary contraction (MVC). Muscle groups whose strength was equal to zero at the initial visit were not included in any of the analyses.

After the initial visit, subjects returned to the Research Clinic two additional times at approximately the same time of day to have their strength reassessed. A period of 3-5 months separated each visit.

Insert Table 2 about here.

Interrater reliability of the three physical therapists was determined for each of the muscle groups. Six subjects (2 polio survivors and 4 individuals with no history of polio) participated in the reliability testing. The strength of each of the 15 muscle groups was tested twice bilaterally by each of the three physical therapists. The average of the two maximal efforts was used for analysis. All strength measurements for a particular subject, gathered for reliability purposes, were performed at the same time of day within a one-month time period.

DATA ANALYSIS

Data were analyzed using the SYSTAT7™ [b] software package. The appropriate descriptive statistics were used to describe the study participants. Intraclass correlation coefficients (ICC[3,1][21]) were used as indices of reliability for the strength measurements.

Repeated measures multivariate analysis of variance (MANOVA), with muscle and time as the repeating factors, was used to determine whether strength changed significantly over time. The original design was to look at general weakening over the entire body. However, a majority of the subjects had missing data or one or more invalid strength values (i.e. due to either pain during measurement or an initial strength value of zero) for at least one muscle group, resulting in their exclusion from the MANOVA. Therefore, we arbitrarily divided the muscles into two groups, upper extremity muscles and lower extremity muscles, in order to increase the sample size for analysis. Out of the 120 subjects who participated in this study, 71 subjects had complete data for the upper extremity group and 65 subjects had complete data for the lower extremity muscle group. There were 40 subjects who had complete data for all muscles and were included in both groups, and 23 subjects who were not included in either group. Based on plots of the various data, which revealed highly skewed distributions, all data were ranked prior to analysis. The strength data were ranked separately within each muscle, across time.

Post-hoc analyses included effect sizes[22] that were calculated based on the difference scores (mean of the strength at visit 1 minus strength at visit 3 across subjects divided by the standard deviation of the differences) for each muscle, using the raw data. The purpose of this analysis was to determine which muscles showed the greatest change in strength and in what direction. In addition, robust slopes were calculated for each subject by muscle using nonlinear regression. This gave us a measure of the rate of change in strength for each individual muscle in each subject. The average slope was then calculated for each subject across all left-sided muscles to get a measure for the slope for the left limb. A similar procedure was followed for the right-sided muscles and finally, across all muscles in each group (i.e. upper vs. lower). Visual inspection of plots and comparison of the means and medians of the slopes for the various muscles showed no evidence of any skewed distributions. Therefore, all analyses done with slopes were parametric.

An analysis of covariance (ANCOVA) was performed for each group with the mean overall slope as the dependent variable and age, gender, weight, and symptom status (i.e. subjects who reported increasing weakness on the polio history form were classified as symptomatic and all others were asymptomatic) as the covariates. Separate ANCOVAs were also performed on each limb with "history of residual weakness in that limb (yes/no)" as a covariate, along with any covariates that were identified as significant predictors for the group slope. Statistical significance for all analyses was defined as $p < 0.05$.

RESULTS

Reliability Testing

All ICC values for interrater reliability of the strength measurements ranged from 0.522 to 0.987, with a median of 0.850. All values were above 0.7 except for right ankle plantar flexion, which had a value of 0.522. The range in ICC values seen in this study is similar to that seen in another study that used a hand-held dynamometer and multiple testers to measure strength in various muscle groups and reported ICCs that ranged from 0.511 to 0.950.[10]

Upper Extremity Strength

The characteristics of the subjects in the upper extremity group are displayed in Table 3. The range in age was 38 to 81 years. The median age at onset of polio was 4 years, and the median number of years since polio was 48, ranging from 38 to 80 years. There were 48 symptomatic subjects and 23 asymptomatic subjects included in this group. A total of 12 (17%) subjects reported residual weakness from the original polio infection in their right arm, and 17 (24%) reported residual weakness in their left arm. In addition, 4 (6%) subjects reported weakness in both arms and 46 (65%) subjects reported no residual weakness in either arm.

Results of the repeated measures MANOVA on upper extremity strength showed that the main effect of time ($p < 0.001$) was highly significant. The mean upper extremity slope across all subjects was negative, which indicated a deterioration in upper extremity strength over time. The results of the MANOVA also revealed a significant muscle by time interaction ($p < 0.001$), indicating that strength decreased more rapidly in some muscles than in others. In order to determine which muscles showed the greatest change in strength over time, parametric effect sizes were calculated across subjects for each muscle. A positive effect size was indicative of a

Insert Table 3 here.

Insert Table 4 here.

decrease in strength over time. As shown in Table 4, all the upper extremity muscles had positive effect sizes. However, these effect sizes ranged from large to small. The largest effect sizes were seen for the right wrist flexor and the left shoulder external rotator.

The results of the ANCOVA on the mean upper extremity slope, with age, gender, symptom status, and weight as covariates, indicated that age was the only significant factor ($p = 0.036$). Age and upper extremity slope were plotted with a linear smoother to show the trend in the relationship between the two variables (Figure 1). As age increased the mean upper extremity slope decreased, indicating an increasing rate of deterioration of strength with increasing age. Age and history of residual weakness in that limb (yes or no) were then input as covariates in separate ANCOVAs for the left and right arms in order to determine if history significantly affected the rate of deterioration of strength. In both arms age was marginally significant (left arm: $p = 0.081$; right arm: $p = 0.050$). However, history of residual weakness was not a significant factor for predicting the slope in either arm (left arm: $p = 0.191$; right arm: $p = 0.587$).

Insert Figure 1 about here.

Lower Extremity Strength

The characteristics of the subjects in the lower extremity group are displayed in Table 5. The range in age was 38 to 76 years. The median age at onset of polio was 5 years, and the median number of years since polio was 48, ranging from 38 to 72 years. There were 43 symptomatic subjects and 22 asymptomatic subjects included in this group. A total of 38 (58%) subjects reported residual weakness from the original polio infection in their right leg and 26 (40%) reported residual weakness in their left leg. In addition, 10 (15%) subjects reported residual weakness in both legs and 11 (17%) subjects reported no residual weakness in either leg.

Results of the repeated measures MANOVA on lower extremity strength indicated that the main effect of time ($p = 0.002$) was significant. The interaction between muscle and time was also significant ($p < 0.001$), indicating that the change in strength over time varied among muscles. Once again, parametric effect sizes were calculated for each muscle (Table 6). The largest effect sizes were seen for the flexor muscles, including the bilateral ankle dorsiflexors, bilateral knee flexors, and bilateral hip flexors, indicating that these muscles showed the largest deterioration in strength. However, the weight-bearing muscles generally showed stable or slightly increasing strength over the study interval.

Similar to the results for the upper extremity group, the mean slope for the lower extremity muscles across all subjects was negative indicating an overall deterioration in strength. Results of the ANCOVA with lower extremity slope as the dependent variable and age, gender, Insert Table 5 about here.

weight, and symptom status as the covariates showed that none of the covariates were significant. Separate ANCOVAs were performed on the slopes for the left and right legs, with history of residual weakness in each leg (yes/no) as the covariate. History was not a significant factor for either leg (left leg: $p = 0.882$; right leg: $p = 0.720$).

In order to determine if there was any evidence of an age effect in the lower extremities, even at a descriptive level, we compared the mean slopes for the lower extremities overall and for the six muscle groups that showed the largest degree of deterioration for two different age groups: a "young" group aged 40-50 years and an "old" group aged 60-70 years (Table 7). The results showed that while the "old" group had a more negative slope, representing a higher rate of deterioration, in the lower extremities overall and in four of the six muscle groups, none of the differences were significant (all $p > 0.05$).

DISCUSSION

Most of the studies that have looked at changes in strength over time among polio survivors have focused their analysis on only one or two muscle groups.[10, 15-18, 20] Most often, the quadriceps or knee extensors are chosen because they are easily isolated for testing, the testing reliability is generally high, and there are many other studies that involve these muscle groups to refer to for comparison.[15,23] In addition, the assumption is made that since the polio virus often affected these muscles, they may, as a result, be overworked. However, the results from these studies are contradictory and leave some question as to whether polio survivors are losing strength at an accelerated rate compared to the general population. There is also some question as to whether the results of from one muscle group can be applied to other muscle groups.

By including a wide range of muscle groups in this study, we were able to look at the strength of the upper body and lower body as a whole in order to determine if there were any signs of overall weakening. Although our study only covered a period of 6-9 months, the results provided objective evidence that muscle strength is deteriorating in polio survivors.

As mentioned earlier, there have been a number of theories proposed to explain deteriorating strength and other symptoms associated with PPS. For example, it has been suggested that the enlarged motor units in polio-affected muscles are more vulnerable to repetitive trauma or overuse than normal muscle units.[24,25,26] One theory involves the ratio of muscle fibers to motor neurons in different muscles.[25] Muscles in the upper extremities, which require fine control, such as those in the hand, have motor neurons that may supply hundreds of muscle fibers. However, in the larger muscles in the lower extremities, one motor neuron may innervate thousands of muscle fibers. Therefore, if the polio virus affected one of these lower extremity muscles, a motor neuron, which originally supported three or four thousand muscle fibers, may have ended up supporting tens of thousands of muscle fibers. Consequently, the loss of motor neurons in larger muscles will have a more significant effect than the loss of the same number of neurons in smaller muscles, like a finger flexor.

Loss of neurons may result from attrition associated with normal aging or as a result of overuse, when the functional demands exceed the capacity of polio-affected muscles. If, in fact, the deterioration in strength was due to "normal" aging, you would expect to see either similar rates of decline in all lower extremity muscles or a higher rate of decline in the muscles most often affected by the polio virus (e.g. the quadriceps or knee extensor muscles). However, the results of this study showed evidence of deterioration of strength in the hip, knee, and ankle flexor muscles rather than the knee extensor muscles.

We can infer that this pattern of deterioration is due to overuse: While there are strategies or "tricks" people can use to compensate for weak extensor muscles, there is no way to protect the flexor muscles, other than not to use them. For example, people may lean against the joint capsule, ligaments etc. to stabilize the knee joint while standing. This saves extensor muscle activity and energy and is also efficient. Polio survivors are masters of this art. Braces are also used in this way to provide external support for weak extensor muscles (e.g. an ankle foot orthosis may limit dorsiflexion to neutral to stabilize a weak calf in the terminal stance phase of gait).

However, there is no substitute for the flexor muscles in lifting a leg against gravity to take a step forward. Therefore, the swing phase or flexor muscles that lift the leg are subject to repetitive stresses that cannot be prevented or reduced with braces or crutches. In fact, when braces are used it is important to consider their weight since they put additional strain on the swing (flexor) muscles, especially when they are at the end of the leg, which acts as a long lever arm relative to the hip.

The results also showed evidence of a deterioration in strength in all the upper extremity muscles measured. The changes did not follow an obvious pattern (i.e. in terms of similar types of muscles changing at similar rates etc.). This is actually not an unexpected finding since the upper extremities do not perform repetitive, stereotypical activities like the legs. Upper extremity strength can be affected by different types of activities and activity levels, hand dominance, use of assistive devices (e.g. canes, crutches), use of manual wheelchair, and the inter-relationships among the muscles in the ipsilateral or contralateral arm.

Although gender, weight, and symptom status have been identified in previous studies as being significant predictors of absolute strength, our results showed that none of these variables were significant predictors of the rate of change in strength for either the upper or lower extremity muscles. In addition, history of residual weakness was not a significant factor for determining the rate of change in strength in either the arms or legs.

Most of the previous studies that looked at the strength in polio survivors over time required their subjects to have strength equal to grade 3+ or greater in the muscle being tested (i.e. gravity-resistant strength). Reasons for this criterion included that the method of testing required gravity-resistant strength, and the investigators felt that it would be too difficult to detect changes in strength in weaker muscles.[23] In the present study, gravity-eliminated testing positions were used which enabled us to include subjects with all levels of strength. This meant that our study population was more representative of polio survivors overall than in many other studies of this type. The only muscle groups that were excluded from the analysis were those with initial strengths equal to zero, since the strength of these muscles would not be expected to change and might otherwise skew the data. Despite the fact that our population included these weaker subjects, we still found evidence of a significant deterioration in strength in the upper and lower extremities.

In addition, most of the previous studies limited their study populations to subjects who were 65 years or younger at the time of the initial evaluation. The population in the current study included subjects who ranged from 38 to 81 years of age. Our results showed that, while age was a significant predictor of deterioration of upper extremity strength, it did not show up as a significant predictor of the rate of deterioration of lower extremity strength. However, there was evidence of an age effect at the descriptive level. However, while the trend was for the older subjects to have a higher rate of deterioration in strength, none of the group differences were significant. It is possible that the age effect in the lower extremities was not as robust as that seen in the upper extremities due to more noise in the data (i.e. there was more variability in strength in the lower extremity muscles). However, it is also possible that since the lower extremities were often affected by the polio virus to a greater degree than the upper extremities, that the rate of deterioration in these muscles is actually related an interaction between the absolute level of strength and activity level rather than age. Unfortunately, the activity survey used in this study gave us only a gross measure of daily activity. Better measures of activity level and information on direct use are needed in order to accurately determine what activities are linked to deterioration of strength and the development of overuse problems in the post-polio population.

Further research is also needed in this area involving larger population samples for longer periods of time. These studies need to go beyond the muscle groups traditionally focused on and look at the long-term changes in the strength of muscles like the flexor muscles in the legs and upper extremity muscles in general. This research is especially important to the post-polio population since good upper extremity function allows many polio survivors to remain active and relatively independent even if their ability to ambulate is lost or severely limited. In addition, studies are needed on the effects of exercise programs and other rehabilitation interventions designed to focus on these muscles in order to determine whether such treatments can effectively slow or even reverse the deterioration process. Also needed is information on the effects of such a program on the subjective feelings of increasing weakness among polio survivors.

CONCLUSIONS

The results of our study suggest that strength is deteriorating among polio survivors and that the muscles most involved are not those that are studied by the majority of researchers. Evidence of a more rapidly progressive decrease in strength with increasing age was seen in the upper extremities. There was also evidence of a decrease in strength of the flexor muscles in the lower extremities for all subjects regardless of age, gender, or weight. These results have interesting implications for treatment programs designed to help polio survivors conserve or improve their existing muscle strength to help them maintain their independence for as long as possible.

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References

1. Halstead LS, Wiechers DO, eds. Late effects of poliomyelitis. Miami, FL: Symposia Foundation, 1985.
2. Cosgrove JL, Alexander MA, Kitts EL, Swan BE, Klein MJ, Bauer RE. Late effects of poliomyelitis. Arch Phys Med Rehabil 1987; 68: 4-7.
3. Wekre LL, Stanghelle JK, Lobben B, Oyhaugen S. The Norwegian polio study 1994: a nation-wide study of problems in long-standing poliomyelitis. Spinal Cord 1998; 36: 280-284.

4. Trojan DA, Cashman N, Shapiro S, Tansey CM, Esdaile JM. Predictive factors for post-poliomyelitis syndrome. Arch Phys Med Rehabil 1994; 75: 770-777.

5. Dalaskas MS. Pathogenic mechanisms of post-polio syndrome: morphological, electrophysiological, virological, and immunological correlations. Ann NY Acad Sci 1995; 753: 167-185.

6. Wiechers DO, Hubell SL. Late changes in the motor unit after acute poliomyelitis. Muscle & Nerve 1981; 4: 524-528.

7. Peach PE. Overwork weakness with evidence of muscle damage in a patient with residual paralysis from polio. Arch Phys Med Rehabil 1990; 71: 248-250.

8. Miller NE, Rao S, Byorsvik B, Mjos OD. High-density lipoprotein and physiological activity. Lancet 1979; 1:111.

9. Agre JC, Rodriquez AA, Sperling KB. Symptoms and clinical impressions of patients seen in a postpolio clinic. Arch Phys Med Rehabil 1989; 70: 367-370.

10. Agre JC, Grimby G, Rodriquez AA, Einarsson G, Knudtsen ER, Franke TM. A comparison of symptoms between Swedish and American post-polio individuals and assessment of lower limb strength: a four-year cohort study. Scand J Rehab Med 1995; 27: 183-192.

11. Windebank AJ, Ltchy WJ, Daube JR, Kurland LT, Codd MB, Iverson R. Late effects of paralytic poliomyelitis in Olmstead County, Minnesota. Neurology 1991; 41: 501-507.

12. Dalakas MC, Elder G, Hallett M Ravits J, Baker M, Papadopoulos M, Albrecht P, Sever J. A long-term follow-up study of patients with post-poliomyelitis neuromuscular symptoms. N Engl J Med 1986; 314: 959-963.

13. Munsat TL, Andres P, Thibideau L. Preliminary observations on long-term muscle force changes in the post-polio syndrome. In: Halstead LS and Wiechers D (Ed.) Research and Clinical Aspects of the Late Effects of Poliomyelitis. Birth Defects: Orig. Series, vol 23, No. 4, March of Dimes, White Plains, NY; 1987: 329-334.

14. Agre JC, Rodriquez AA. Strength in postpolio subjects: a two year follow-up study (abstract). Arch Phys Med Rehabil 1990; 71: 792.

15. Agre JC, Rodriquez AA. Neuromuscular function in polio survivors at one-year follow-up. Arch Phys Med Rehabil 1991; 72: 7-10.

16. Munin MC, Jaweed MM, Staas WE Jr, Satinsky AR, Gutlerez G, Herbison GJ. Post-poliomyelitis muscle weakness. A prospective study of quadriceps strength. Arch Phys Med Rehabil 1991; 72: 729-733.

17. Grimby G, Hedberg M, Henning G-B. Changes in muscle morphology, strength and enzymes in a 4-5 year follow-up of post-polio subjects. Scand J Rehabil Med 1994; 26: 121-130.

18. Grimby G, Kvist H, Grangard U. Reduction in thigh muscle cross-sectional area and strength in a 4-year follow-up in late polio. Arch Phys Med Rehabil 1996; 77(10): 1044-1048.

19. Ivanyi B, Nelemans PJ, de Jongh, B, Ongerboer de Visser, BW, de Visser, M. Muscle strength in postpolio patients: a prospective follow-up study. Muscle & Nerve, 1996; 19: 738-742.

20. Rodriquez AA, Agre JC, Franke TM. Electromyographic and neuromuscular variables in unstable postpolio subjects, stable postpolio subjects, and control subjects. Arch Phys Med Rehabil 1997; 78: 986-991.

21. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. Psych Bull 1979; 86(2): 420-428.

22. Cohen J. Statistical power analysis for the behavioral sciences. Hillsdale, NJ: Lawrence Erlbaum Associates, 1988.

23. Agre JC, Rodriquez AA. Neuromuscular function: comparison of symptomatic and asymptomatic polio subjects to control subjects. Arch Phys Med Rehabil 1990; 71: 545-551.

24. Buchthal F. Some aspects of the pathologic physiology of poliomyelitis. In: Poliomyelitis: Papers and Discussions Presented at the First International Poliomyelitis Conference. Philadelphia, PA: JB Lippincott Company, 1949.

25. Trojan DA, Cashman NR. Current Trends in Post-Poliomyelitis Syndrome. New York, NY: Milestone Medical Communications, 1996.

26. Einarsson G. Muscle conditioning in late poliomyelitis. Arch Phys Med Rehabil 1991; 72: 11-14.

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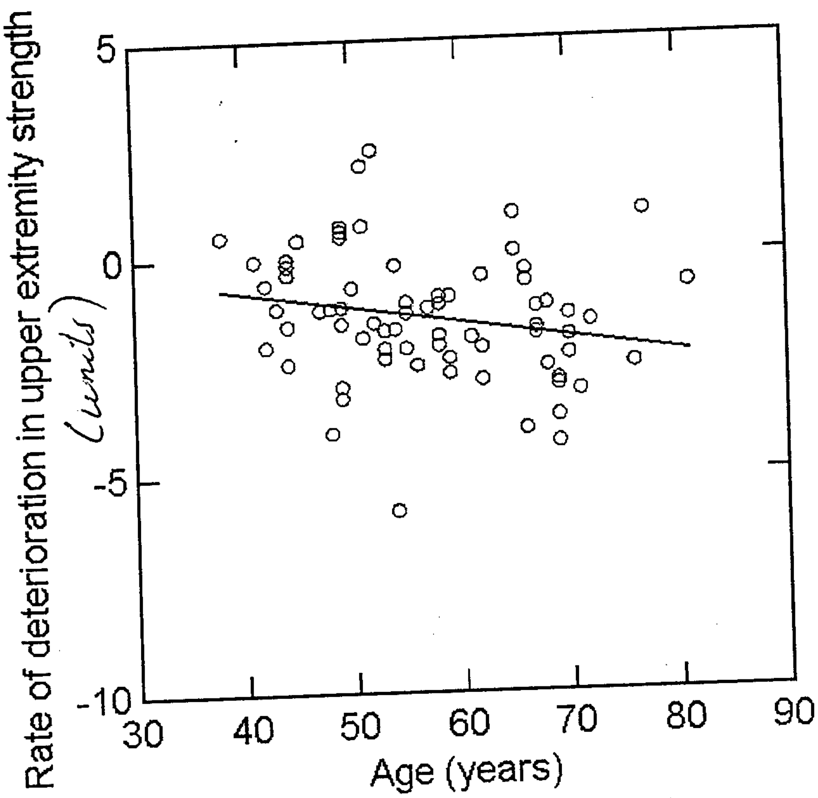
Rate of deterioration in upper extremity strength (units)
5
0
-5
-10
30
40
50
60
70
80
90
Age (years)